



## **PULSE SHAPER CIRCUIT FOR SENSE AMPLIFIER ENABLE DRIVER**

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### **BACKGROUND**

#### **Field of the Invention**

[1001] The present invention relates generally to integrated circuits and, more particularly, to sense amplifier enable drivers.

#### **Description of the Related Art**

[1002] Typically, modern semiconductor memories (whether embodied in a memory integrated circuit or incorporated in larger designs, e.g., as cache memory of a processor integrated circuit) employ differential bit lines and some sort of differential amplifier or sensing circuit in their design. Such differential amplifier and sensing circuits are commonly known as sense amplifiers (sense amps) and a wide variety of sense amplifier designs are known in the art, including current sensing and voltage sensing variations.

[1003] Generally, when designing sense amplifiers, great care is taken to optimize timing and balance. Typically, a signal such as a sense amplifier enable (SE) is used to time sense amplifier operation. For example, one state of an SE signal is often used to equalize sense amplifier nodes for a period that allows differential bit-lines to develop sufficient voltage differential to support sensing. Once the differential bit-lines have developed sufficient differential, SE is transitioned to cause the sense amplifier to actually sense the developed differential.

[1004] Generally, if the equalization period defined by SE transitions is too short, then the bit-lines may not develop sufficient differential for the sense amplifier to correctly sense the data being read from an addressed memory cell. On the other hand, if too much time is allowed for SE, then access time of the memory circuit is

increased and achievable operating frequency (or at least memory access bandwidth) may be reduced. Therefore, in high-speed designs, the SE signal delay path is designed to deliver the SE transition at just the right time to ensure that correct data is being read, while aiming to minimize shortest cycle time.

[1005] In some typical sense amplifier designs, the equalization operation and the sensing operation have different requirements. For example, it may be preferable to limit the slope of the SE signal to make the sensing operation more reliable, e.g., by slowing the rate of discharging a common node to reduce false switching inside the sense amplifier but maintaining the rate of discharging the common node so that it is faster than the rate of discharging a bit-line. In addition, the equalization operation is preferably disabled prior to the sensing operation in order to allow a signal to develop. One technique for generating control signals having these different timing requirements uses two separate drivers. However, if two separate drivers are used, a fixed relationship between the signals becomes difficult to maintain due to circuit matching discrepancies, e.g., device mismatches produced by process variations. Accordingly, new techniques are desired to address generation of sense amplifier control signals.

## **SUMMARY**

[1006] A sense amplifier pulse shaping circuit maintains a relationship between a sense amplifier enable signal and a sense amplifier equalization enable signal while disabling equalization prior to evaluation and disabling evaluation prior to equalization. In some embodiments of the present invention, a sense amplifier pulse shaper circuit generates a sense amplifier equalization control signal and a sense amplifier enable signal. The sense amplifier equalization control signal has a rising transition effectively earlier than the rising transition of the sense amplifier enable signal. The sense amplifier enable signal has a falling transition effectively earlier than the falling transition of the sense amplifier equalization control signal. The sense amplifier equalization signal is discharged into the sense amplifier enable signal.

[1007] In some embodiments of the present invention, an integrated circuit includes an input node, a first switch coupled to the input node, a second switch coupled to the input node, an impedance coupled to the first and the second switches,

a sense amplifier equalization enable node, and a sense amplifier evaluation enable node. The sense amplifier equalization enable node receives a first signal. The sense amplifier evaluation enable node receives a second signal. The nodes are coupled to the impedance and respective ones of the first and second switches. A first transition of the first signal is effectively earlier than a first transition of the second signal and a second transition of the second signal is effectively earlier than a second transition of the first signal.

[1008] In some embodiments of the present invention, a method for operating a sense amplifier includes substantially matching delays of a first control signal and a second control signal. The first control signal turns on and turns off an equalization of the sense amplifier. The second control signal turns on and turns off the sense amplifier. The method includes effectively turning off equalization of the sense amplifier before effectively turning on a sensing operation. The method includes effectively turning off the sensing operation before effectively turning on the equalization of the sense amplifier. The method includes discharging the first control signal into the second control signal.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

[1009] The present invention may be better understood, and its numerous objects, features, and advantages made apparent to those skilled in the art by referencing the accompanying drawings.

[1010] **FIG. 1**, labeled as prior art, illustrates an exemplary sense amplifier and enable driver.

[1011] **FIG. 2** illustrates an exemplary sense amplifier and enable driver configured consistent with the present invention.

[1012] **FIG. 3** illustrates exemplary control signals consistent with the present invention.

[1013] The use of the same reference symbols in different drawings indicates similar or identical items.

**DESCRIPTION OF THE PREFERRED EMBODIMENT(S)**

[1014] The description herein focuses on a sense amplifier enable driver that generates a sense amplifier enable signal and a sense amplifier equalization enable signal having different timing requirements but matches characteristics of the two signal paths. Referring to FIG. 1, circuit 100 illustrates an exemplary sense amplifier and enable driver. Sense amplifier 106 is coupled to enable driver circuit 108, which includes p-type transistor 102 and n-type transistor 104. Input SE\_L enables both an equalization operation and an evaluation (i.e., sensing) operation of sense amplifier 106. Node 110 drives both PR\_L and SE\_H. In circuit 100, signal PR\_L is an active-low signal for precharging sense amplifier 106 and SE\_H is an active-high signal for enabling the evaluation operation of sense amplifier 106. However, in other sense amplifier and enable driver designs, the equalization operation may discharge certain nodes, rather than precharge certain nodes, the equalization operation enable may be an active-high signal, and/or the evaluation operation enable signal may be an active low signal and the invention described herein may be modified consistent with these design variations.

[1015] The design illustrated in FIG. 1 uses the same signal for driving PR\_L and SE\_H, resulting in identical rise times and fall times for the two signals. However, additional control over these transitions of PR\_L or SE\_H may be desirable, e.g., to limit the slope of the SE signal or to disable the equalization operation prior to the sensing operation. It may also be desirable to maintain a fixed timing relationship between PR\_L and SE\_H, but vary the relative transition points of these two signals.

[1016] Circuit 200 of FIG. 2 illustrates exemplary sense amplifier 106 and enable driver 210. Enable driver 210 includes p-type transistor 202, n-type transistor 206 and impedance 212. Impedance 212 includes p-type transistor 204 and n-type transistor 208. Transistors 204 and 208 are configured in an 'ON' state. The gate of transistor 204 is coupled to ground and the gate of transistor 208 is coupled to power. Alternatively, transistors 204 and 208 may be turned on based in part on the input signal SE\_L, e.g., the gates of transistors 204 and 208 may be coupled to SE\_L to independently control the rise and fall times of PR\_L and SE\_H, or the gates of transistors 204 and 208 may be coupled to nodes 216 and 214, respectively, to limit

the voltage swing of PR\_L and SE\_H if the sense amplifier does not require a full voltage swing. Impedance 212 is not limited to an n-type transistor and a p-type transistor, but may be any suitable circuit.

[1017] Input SE\_L controls both an equalization operation and an evaluation operation of sense amplifier 106. A signal on node 214 drives PR\_L and a signal on node 216 drives SE\_H. In circuit 200, signal PR\_L is an active-low signal that substantially turns on and substantially turns off a precharge operation in sense amplifier 106 and SE\_H is an active-high signal that substantially turns on and substantially turns off the evaluation operation of sense amplifier 106. However, other design variations include a discharge equalization operation, and active-high equalization operation enable signal, and/or an active-low evaluation operation enable signal. Note that in circuit 200, the values of PR\_L and SE\_H have opposite polarity from the value of SE\_L, i.e., when SE\_L = '1,' PR\_L and SE\_H = '0' and when SE\_L = '0,' PR\_L and SE\_H = '1.'

[1018] When SE\_L transitions high (i.e., SE\_L = '1') transistor 202 substantially turns off and transistor 206 substantially turns on. Transistor 206 discharges node 216 and, in series with the parallel combination of transistors 204 and 208, discharges node 214 (i.e., PR\_L and SE\_H = '0'). Transistors 204 and 208 are sized to adjust the slope of the falling transition of PR\_L. In addition, transistors 204 and 208 introduce a delay (measured from mid-point to mid-point) between the transition edges of PR\_L and SE\_H.

[1019] When SE\_L transitions low, transistor 202 substantially turns on and transistor 206 substantially turns off. Transistor 202 charges nodes 214 and, in series with the parallel combination of transistors 204 and 208, charges node 216, and nodes 214 and 216 transition high. Transistors 204 and 208 are sized according to a desired slope of the rising transition of SE\_H. In addition, transistors 204 and 208 are also sized according to a desired delay (measured from mid-point to mid-point) between the transition edges of PR\_L and SE\_H.

[1020] Waveforms generally illustrating operation of enable driver 210 are included in FIG. 3. At time t1, SE\_L has already begun to transition low, and PR\_L begins to transition high. At a later time, time t2, SE\_H begins to transition high. At

time t3, PR\_L has completed transitioning high, and at a later time, time t4, SE\_H has finished transitioning high. Thus, PR\_L substantially turns off the precharge operation of sense amplifier 106 prior to substantially turning on the evaluation operation of sense amplifier 106. The slopes of PR\_L and SE\_H may vary from each other during the transition from GND to VDD.

[1021] At time t5, SE\_L has already begun transitioning from GND to VDD and SE\_H begins to transition from VDD to GND. PR\_L begins transitioning from VDD to GND at a later time, time t6. The transition of SE\_H from VDD to GND completes at time t7. The transition of PR\_L from VDD to GND completes at a later time, time t8. Thus, SE\_H disables the evaluation operation of sense amplifier 106 prior to the enabling of the evaluation operation of sense amplifier 106. The slopes of PR\_L and SE\_H may vary from each other during the transition from VDD to GND. Note that SE\_H and PR\_L are substantially in-phase, i.e., SE\_L and PR\_L overlap at VDD and GND for a substantial interval of time in relation to the absolute time these signals are at VDD and GND.

[1022] In an exemplary design, transistors 202, 204, 206, and 208 have schematic widths of 5.52, 2.00, 3.00, and 4.56, respectively in a 0.13 micron process technology. In another exemplary design, transistors 202, 204, 206, and 208 have schematic widths of 3.00, 1.20, 1.20, and 3.00, respectively. For a circuit operating at a nominal voltage of 1.1V and a clock speed of 1.8 GHz, the rising transition of SE\_H may have a several picosecond delay from the low-high transition of PR\_L. For a circuit operating at 1.8 GHz, the low-high transition of SE\_H may have a several picosecond delay from the low-high transition of PR\_L, e.g., in one realization of the invention, the rise times (measured from 20%-80% of the signal voltage) of SE\_H and PR\_L are 19.8ps and 13.6ps, respectively, with a delay (measured from mid-point to mid-point) of 5.7ps and the fall times (measured from 20%-80% of the signal voltage) of SE\_H and PR\_L are 15.0ps and 14.0ps, respectively, with a delay (measured from mid-point to mid-point) of 8.4ps. Transistor sizes may vary with the target process technology and set of timing constraints. The sizes described above are exemplary for the particular process technology and set of timing constraints are not meant to be limiting.

[1023] While circuits and physical structures are generally presumed, it is well recognized that in modern semiconductor design and fabrication, physical structures and circuits may be embodied in computer readable descriptive form suitable for use in subsequent design, test, or fabrication stages as well as in resultant fabricated semiconductor integrated circuits. Accordingly, claims directed to traditional circuits or structures may, consistent with particular language thereof, read upon computer readable encodings and representations of same, whether embodied in media or combined with suitable reader facilities to allow fabrication, test, or design refinement of the corresponding circuits and/or structures. Finally, structures and functionality presented as discrete components in the exemplary configurations may be implemented as a combined structure or component. These and other variations, modifications, additions, and improvements may fall within the scope of the invention as defined in the claims that follow.